United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

Research Paper
PNW-RP-384

Highly Stocked Coniferous Stands on the Olympic Peninsula: Chemical Composition and Implications for Harvest Strategy

Susan N. Little and Dale R. Waddell

Authors

SUSAN N. LITTLE and DALE R. WADDELL are research foresters, Forestry Sciences Laboratory, P.O. Box 3890, Portland, Oregon 97208.

Abstract

Little, Susan N.; Waddell, Dale R. 1987. Highly stocked coniferous stands on the Olympic Peninsula: chemical composition and implications for harvest strategy. Res. Pap. PNW-RP-384. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 29 p.

This report presents an assessment of macronutrients and their distribution within highly stocked, stagnant stands of mixed conifers on the Quilcene Ranger District, Olympic National Forest, northwest Washington. These stands consisted of predominantly three species: western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), and western redcedar (*Thuja plicata* Donn ex D. Don). Preliminary investigation suggests that the living crown contains a small portion of the nutrient capital on the site. Extracting this material from the site during harvest or site preparation should not pose a threat to future production of biomass. Bioassays suggested that no macronutrients were deficient for growth of Douglas-fir seedlings. This study was one of several conducted on the Quilcene Ranger District for a better understanding of the economics, technology, and impacts of harvesting highly stocked, small-diameter timber.

Keywords: Whole-tree logging, nutrient budgets, site productivity, Washington (Olympic Peninsula), Olympic Peninsula—Washington.

Summary

In this paper, we investigate the amount and distribution of nitrogen, phosphorus, potassium, calcium, and magnesium within highly stocked, stagnant stands (doghair) of mixed conifers on the Quilcene Ranger District, Olympic National Forest, northwest Washington. These stands consisted of predominantly three species: western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), and western redcedar (*Thuja plicata* Donn ex D. Don).

The amount of biomass in live trees at Quilcene is within the range of biomass values reported for other second-growth stands. Because of the vast quantity of dead material on the study sites, total aboveground biomass is comparable to that of old-growth stands. Likewise, nutrient capital for doghair stands compares favorably with that for other forest types. A large portion of the biomass and capital, however, is contained in dead material and in the forest floor.

Availability of soil nutrients was explored through bioassays of the surface soils. No macronutrients were found to be deficient for the juvenile growth of Douglas-fir.

Whole-tree harvesting should not adversely affect nutrient supplies on these sites. Care should be taken during harvest and site treatment, however, to protect the nutrient capital in dead material and in the forest floor.

Contents

Introduction

The Quilcene Ranger District, Olympic National Forest, has about 8000 ha of forest lands that are popularly known as doghair. These stands are stagnant and highly stocked—6,000 to 100,000 trees/ha—and have small average stem diameters. These stands comprise western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), and western redcedar (*Thuja plicata* Donn ex D. Don), ranging from 30 to 90 years old with average diameter at breast height (d.b.h.) less than 20 cm. Some of these stands are being whole-tree harvested; the intention is to convert to stands capable of producing saw timber. After harvest, some of these sites will be burned to reduce fire hazard and to expose mineral soil, which facilitates planting. The long-term impacts of these management options are not known. This study was designed to determine the distribution of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) in ecosystem components (crowns, boles, woody debris, forest floor, and soil) and any deficiency of these nutrients in the soil.

The study is part of a broader effort to investigate the technical and economic feasibility of harvesting doghair for fiber and fuel.[1/] Equations for predicting the biomass of trees and the average density of wood and bark in stems, essential for determining the nutrient content of trees, have been developed for these sites and are presented in previous reports (Pong and Waddell 1986).

Nutrient Exports From Whole-Tree Harvesting

Land managers have expressed concern that the removal of tree crowns during timber harvest may result in critical losses of nutrients and thereby reduce the future productivity of the site. The amount of nutrient capital contained in the crowns depends on species, age, site, and stand density. The relative contribution of crown material left on the site to future productivity depends on the amount of nutrients in the crowns, the amount and availability of nutrients in the forest floor and soil, and the rate of decomposition (Kimmins 1977). Estimates of the amount of N, P, and K in ecosystem components have been developed for some conifer forest types in the Pacific Northwest (Bigger and Cole 1983, Brown 1977, Grier and others 1974) (table 1, fig. 1). Morrison and Foster (1979) published estimates of N, P, K, Ca, and Mg for jack pine (*Pinus banksiana* Lamb.) stands in Ontario. Few studies, however, have been able to relate the amount of nutrients in tree boles and crown to the effects on productivity of removing that capital during harvest.

Some authors suggest that the effect of intensive harvests on site productivity is related to the age and productivity of the stand at the time of harvest (Cromack and others 1978, Kimmins 1977, Norton and Young 1976, Van Hook and others 1982). The age of the stand affects the amount and distribution of nutrients in the biomass. Switzer and others (1968) found that the amount of N in the foliage of *Pinus taeda* L. (loblolly pine) decreased in stands older than 15 years, whereas the amount of N in the stem and branch material continued to accumulate. They also discovered a decrease in the rate of storage (mean annual accumulation) for N, P, K, Ca, and Mg in the aboveground biomass with an increase in age.

[1/] Biomass estimation, production cost, and nutrient impacts of converting overstocked (doghair) stands to energy and fiber products. Interagency Agreement DE-AI79-84BP17609 between U.S. Department of Energy and USDA Forest Service. On file with Biomass Management and Utilization for Fiber and Energy Project, Portland, OR.

Table 1—Published biomass and nutrient budgets for coniferous forest types

Vegetation type, location, and source	Age	Component	Biomass	N	P	K	Ca	Mg
	Years		*Megagrams/ hectare*	*Kilograms / hectare*				
Douglas-fir: Pack Forest, WA (high site) (Bigger and Cole 1983)	53	Crown	37	250	40	101	—	—
		Bole	281	478	56	225	—	—
		Total tree above ground	318	728	96	326	—	—
		Forest floor	18	214	21	26	—	—
		Total above ground	336	942	117	352	—	—
		Soil to 50 cm	—	2066	—	—	—	—
Douglas-fir: Pack Forest, WA (low site) (Bigger and Cole 1983)	53	Crown	31	164	29	60	—	—
		Bole	134	161	27	81	—	—
		Total tree above ground	165	325	56	141	—	—
		Forest floor	14	187	19	27	—	—
		Total above ground	179	512	75	168	—	—
		Soil to 50 cm	—	483	—	—	—	—
Douglas-fir: H.J. Andrews Experimental Forest, OR (Grier and others 1974)	450	Crown	57	124	30	119	336	—
		Bole	473	189	12	123	284	—
		Total tree above ground	530	313	42	242	620	—
		Logs (residue)	55	132	9	20	80	—
		Litter (forest floor)	44	434	61	50	363	—
		Total above ground	629	879	112	312	1063	—
		Soil to 100 cm	—	4300	29	1	5500	—
Douglas-fir: Thompson Research Center, WA (Grier and others 1974)	37	Crown	31	163	41	100	179	—
		Bole	140	125	19	96	117	—
		Total tree above ground	171	288	60	196	296	—
		Logs (residue)	6	14	2	8	17	—
		Litter (forest floor)	16	161	24	24	120	—
		Total above ground	193	463	86	228	433	—
		Soil to 100 cm	—	2809	3871	234	741	—
Larch/fir: Ellensburg, WA (Brown 1977)	Uneven	Crown	72	288	67	258	427	46
		Bole	231	168	48	143	324	45
		Total tree above ground	303	456	115	401	751	91
		Dead (residue)	95	27	10	26	88	11
		Forest floor	32	308	31	25	354	423
		Total above ground	430	791	156	452	1193	325
		Soil to 60 cm	—	3314	25	657	3293	560
Larch/fir: Tonasket, WA (Brown 1977)	Uneven	Crown	30	141	26	138	218	16
		Bole	64	49	15	31	93	9
		Total tree above ground	94	190	41	169	311	25
		Dead (residue)	46	33	5	17	31	1
		Forest floor	29	327	29	30	457	17
		Total above ground	169	550	75	216	799	43
		Soil to 60 cm	—	6961	33	1716	12152	924
Jack pine: Ontario, Canada (Morrison and Foster 1979)	65	Crown	24	98	10	39	40	7
		Bole	90	82	4	50	87	12
		Total tree above ground	114	180	14	89	127	19
		Forest floor	26	283	13	680	396	157
		Total above ground	140	463	27	769	523	176
		Soil (A and B horizons)	—	2920	2152	80637	34406	21075

— not reported.

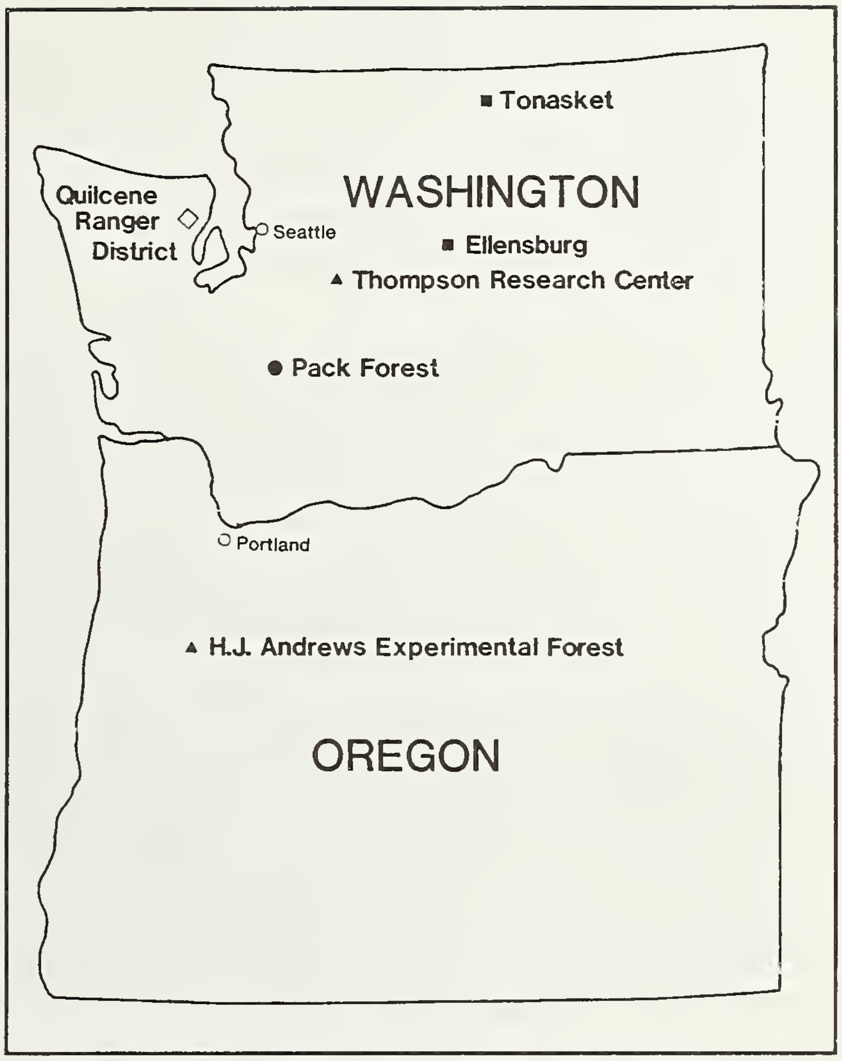

Figure 1—Location of Quilcene (◇) and study sites reported by Bigger and Cole (1983) ●, Brown (1977) ■, and Grier and others (1974) ▲.

Work by Bigger and Cole (1983) suggests that crown material may hold a larger portion of aboveground nutrient capital on sites with lower productivity (table 1). On their Douglas-fir site with low productivity (low site), the crown component comprised 36 percent of the total N but only 16 percent on the site with high productivity (high site). This may indicate the importance of leaving crown material on poor sites to avoid depleting the existing nutrient capital. Two years after harvesting and planting, Bigger and Cole measured significantly less seedling growth on the sites (both high and low) that were whole-tree harvested than on the sites from which only boles were removed. Reduction in diameter growth was 4 percent on the high site and 21 percent on the low site, and the response in height growth was similar. Moisture and temperature extremes caused by lack of shade may have contributed to the reduction in growth on the sites that were whole-tree harvested.

History of Doghair on the Quilcene Ranger District

The current doghair stands were established after severe wildfires between 1891 and 1925 (Quilcene Ranger District, fire records). Most of the sites regenerated naturally. Planted sites are also overstocked. A large amount of woody debris is on these sites. Most of the western hemlock and Douglas-fir trees killed by fire have been incorporated into the forest floor; the larger western redcedar remain intact on the surface. Large amounts of unincorporated debris on the forest floor indicate that decomposition is slow, and nutrients bound in the forest floor are relatively unavailable to the current stand (Vitousek 1981).

Soils Underlying the Doghair Stands

The soils underlying these doghair stands are Entisols and Inceptisols that developed on deposits from continental glaciers (Soil Concept 22, Jennings and others 1982). These geologic materials vary in particle size and shape, the orientation of the strata, the degree of compaction, and their resistance to weathering. The soils are weakly developed (Birkeland 1977), lacking structure and differentiation of horizons; this has resulted in soils that are highly variable even within small areas of similar relief (Miller 1979). The soil is thought to be deficient in N and some micronutrients such as copper (Cu) and iron (Fe) and with perhaps toxic levels of manganese (Mn).[2/]

Objectives

The objectives of this study were twofold. The first objective was to estimate the amount of N, P, K, Ca, and Mg within components of the ecosystem: tree crowns, boles, and bark; dead trees and logs; forest floor and soil. Roots above mineral soil were considered to be part of the forest floor. Roots less than 2 mm within mineral soil were considered to be part of the soil resource. Large roots were not sampled. Levels of precision were not predetermined because sample size was limited by the cost of chemical analyses. The second objective was to determine which, if any, of those nutrients are deficient in the soil. Bioassays of individual sites with local Douglas-fir stock were used to test for deficiencies.

Methods

General Approach

Six sites on the Quilcene Ranger District were chosen for study and treated as one population for determination of biomass and nutrient capital. Two of the sites were designated harvest units on the Eightmile Creek drainage; the other four sites were delineated by stocking level on the Snow Creek drainage (fig. 2). Stand structure and biomass estimates were developed by Pong and Waddell (1986). Stocking levels for each site are summarized in table 2. A subsample of 33 live trees and 25 dead trees was selected from the biomass sample for nutrient analyses. Soil profiles were described at 25 locations over the six sites, and samples were taken at each location for nutrient analyses. Bioassays run on separate soil samples from four sites (Eightmile Creek 13, Eightmile Creek 19, Snow Creek 1, and Snow Creek 3) were used to test for nutrient deficiencies.

Site Description

The sites were inventoried with 60 circular 81-m² plots on a 61-m square grid. Data from these plots were used to build stand tables, which contain the number of trees within 2.5-cm-diameter classes for each of the three species. Dead trees of all species were combined into one category (the fourth "species") and sampled over the same diameter classes. Sample trees were randomly selected from the trees tallied on the 81-m² plots so that one live tree was selected for each species-diameter class. At least two dead trees were selected for each diameter class.

[2/] Wes Jennings, forest soil scientist, Olympic National Forest, Olympia, WA, personal communication, May 1984.

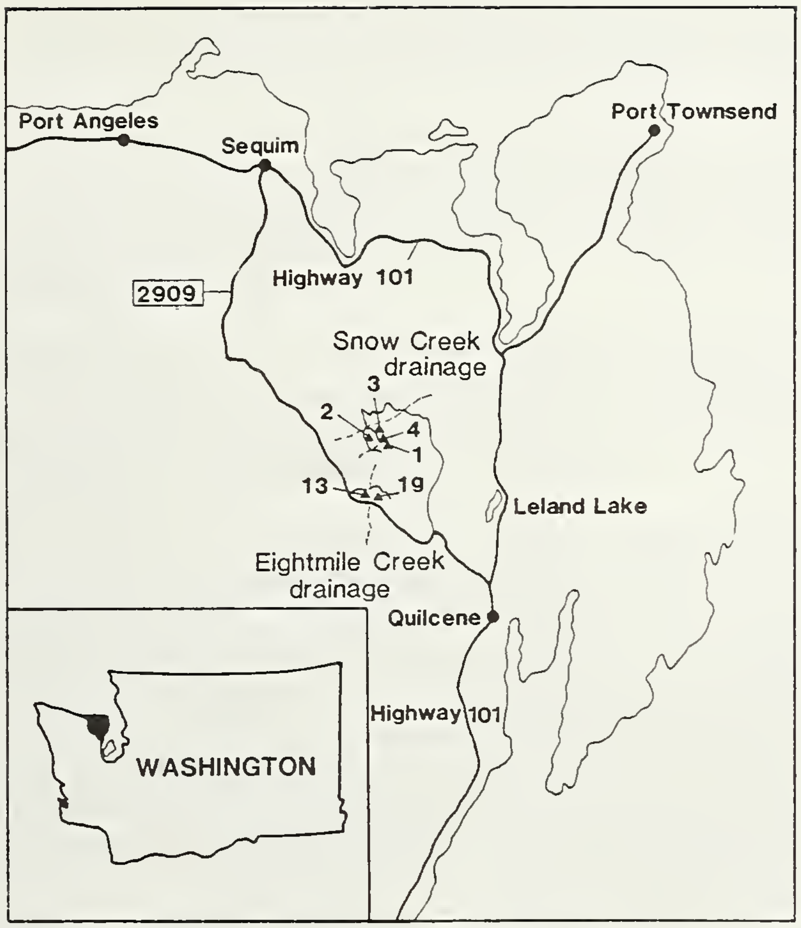

Figure 2—Location of study areas on the Quilcene Ranger District, Olympic National Forest.

Table 2—Stocking levels of study sites on the Quilcene Ranger District

Site	Live trees	Live and standing dead trees
	Trees / hectare	
Eightmile Creek 13	22,800	39,200
Eightmile Creek 19	6,400	8,400
Snow Creek 1	2,600	4,500
Snow Creek 2	5,300	8,000
Snow Creek 3	2,400	6,000
Snow Creek 4	5,300	10,200

Chemical Composition of Stands

All trees were sampled in August and September 1984. All biomass components were weighed in the field. Samples were taken at 1.5-m intervals along the bole for determination of moisture content. Figure 3 illustrates where samples were taken from a tree for determination of nutrient concentrations. Two disks were sampled from the bole—one at 1.39 m above the root collar and one at the base of the live crown. The disks then were separated into bark and wood, air dried, and analyzed. The crown was

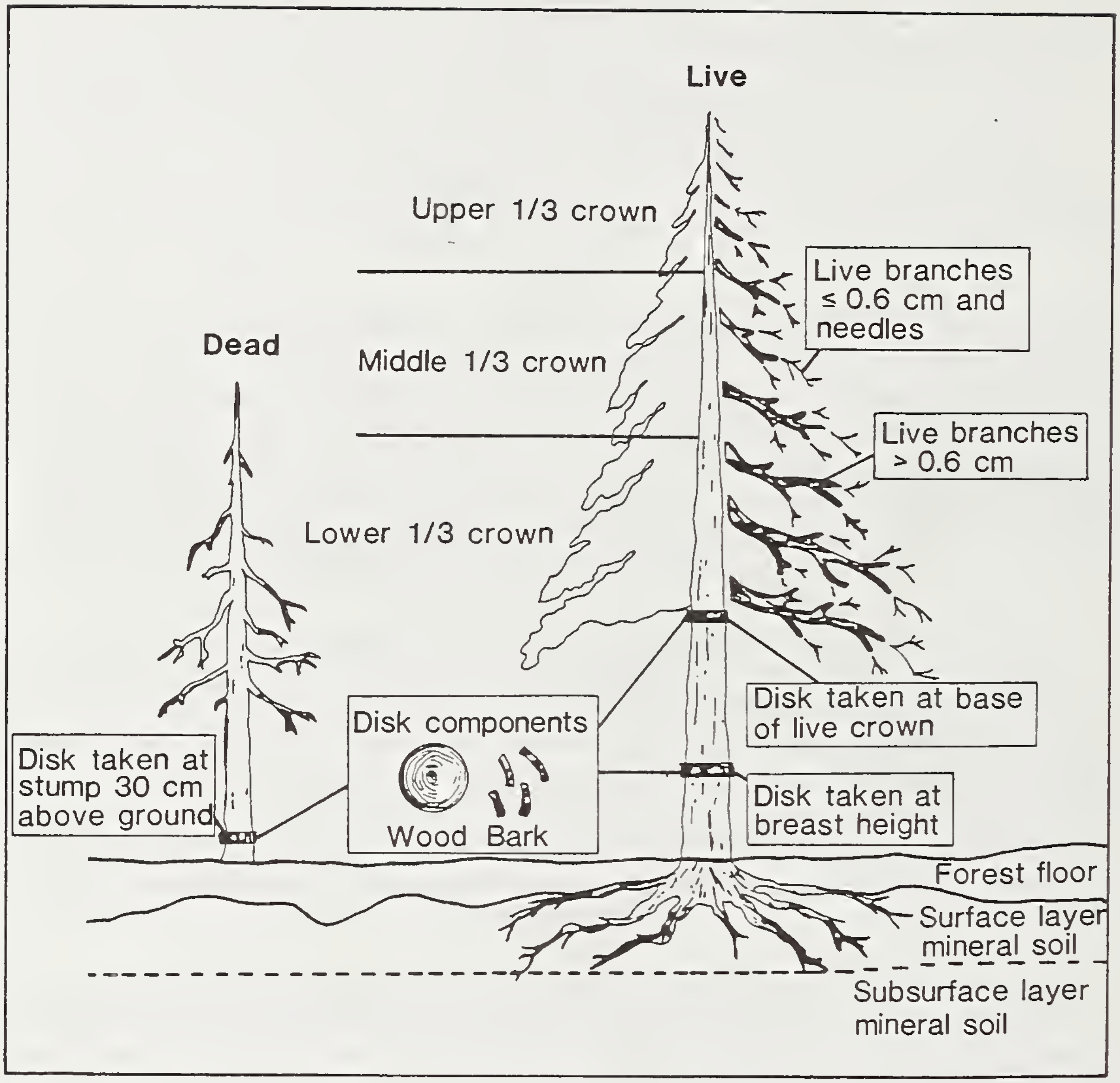

Figure 3—Components sampled from live and dead trees and soil for analyses of nutrient concentrations.

divided into six strata by size and vertical position in the tree: coarse (branches more than 0.6 cm in diameter) and fine (all materials less than 0.6 cm); lower, middle, and upper one-third of the crown. Trees less than 8 cm in d.b.h. had the same strata for size, but only two vertical strata—lower one-third and upper two-thirds of the crown. Each stratum was weighed, chipped, mixed, and sampled once for determination of moisture content and once for nutrient analyses.

Chemical analyses were conducted for N, P, K, Ca, and Mg by the Oregon State University Department of Forest Science. Samples for N and P analyses were digested by the micro-Kjeldahl method (350 °C; K_2SO_4, $CuSO_4$, and Se as catalysts) and analyzed with Scientific Instrument Continuous Flow Analyzer 200.[3/] Samples for

[3/] Mention of commercial names is for the information of the reader and does not constitute an official endorsement by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

cation (K, Ca, Mg) analyses were digested with perchloric acid and analyzed by Perkin-Elmer 4000 Atomic Absorption Spectrophotometer.

The concentration of each nutrient was multiplied by the dry weight of the component from which it was sampled. Nutrient weights were then summed for all components, resulting in a total capital for each tree. Total nutrient capital in aboveground biomass was estimated by applying these results to the stand tables generated from the inventory of the sites.

Residue biomass was estimated from line-intersect data taken on 240 15.24-m lines connecting the inventory plots (Brown 1974). Average nutrient concentrations determined for the dead trees were applied to the total biomass of residue per hectare for an estimate of nutrient capital in the residue.

A soil profile was described in each plot containing a sample tree. Bulk density was sampled at each plot in the surface and subsurface horizons by use of procedures outlined by Blake (1965). A sample was taken for determination of chemical concentrations from each of three layers: the forest floor, surface, and subsurface horizons (effective rooting depth). Nitrogen and phosphorus were determined by the same procedures used for plant materials; K, Ca, and Mg were determined by ammonium acetate extraction (Chapman 1965). Soil capital for each layer was calculated as the product of the concentration of nutrient, the bulk density, and the thickness of the layer. Soil capital was then averaged over all profiles for each nutrient.

Deficiency Test: Bioassay Design

The bioassay technique uses the biomass of plant material grown under controlled conditions to evaluate the availability of a given nutrient or set of nutrients. The technique assumes that, because other variables affecting the growth of the plant (such as water, light, and temperature) are controlled in the laboratory, differences in plant growth (weight of seedlings) between treatments can be attributed directly to the treatment (level of nutrient added or omitted).

Douglas-fir seedlings from seed collected on the Quilcene Ranger District[4/] were used in the bioassay. Bioassays were completed for four sites: Eightmile Creek 13 and 19 and Snow Creek 1 and 3. Each bioassay consisted of 12 treatments (nutrient combinations) with five replicates per treatment (table 3). The quantity of fertilizer selected for each treatment was based on previous studies conducted on soils in the Pacific Northwest (Gessel and others 1979, Walsh and Beaton 1973).[5/] Table 4 lists the form and dose of fertilizers used in the bioassays.

Each soil sample was dried, sieved to less than 1.3 cm with fines of organic matter included, and partitioned into 60 subsamples of equal weight. Dry fertilizers (KCl, $CaCO_3$, $MgCl_2$, S, and $CuCl_3$) were added directly to the soils. Each subsample was placed in a 3.8-liter plastic pot with saucer. NH_4NO_3 was added three times during the

---

[4/] Seed stock number 926-82/205-09-221-02000-2.5-82-SIA, obtained from the USDA Forest Service Wind River Nursery, near Carson, WA.

[5/] Donald Hauxwell, soil scientist, Humboldt State University, Arcata, CA, personal communication, May 1984; Richard E. Miller, principal soil scientist, Forestry Sciences Laboratory, Olympia, WA, personal communication, June 1984.

Table 3—Nutrients added for each treatment of the bioassay

Treatment[1/]	Nutrients added
All nutrients (N1)	N1, P, K, Ca, S, Mg, Cu
All nutrients (N1)	N2, P, K, Ca, S, Mg, Cu
–N	P, K, Ca, S, Mg, Cu
–P	N1, K, Ca, S, Mg, Cu
–K	N1, P, Ca, S, Mg, Cu
–Ca	N1, P, K, S, Mg, Cu
–S	N1, P, K, Ca, Mg, Cu
–Mg	N1, P, K, Ca, S, Cu
–Cu	N1, P, K, Ca, S, Mg
Control+N1	N1
Control+N2	N2
Control	None

[1/] "–" refers to nutrient excluded from treatment.

Table 4—Form and dose of nutrients used in bioassay treatments

Nutrient added	Form	Dose	
		Kilograms/ hectare	*Pounds/ acre*
N1	NH_4NO_3	184.0	200
N2	NH_4NO_3	368.0	400
P	P_2O_4	92.0	100
K	KCl	92.0	100
Ca	$CaCO_3$	92.0	100
Mg	$MgCl_2$	46.0	50
S	S	46.0	50
Cu	$CuCl_3$	4.6	5

experiment to avoid germination suppression. Phosphorus was added in aqueous solution after pots were thinned to three seedlings.

Each bioassay was configured in a completely random design. Thousand-watt halide lamps (phosphorus coated) were used with a photoperiod of 18 hours per day. Pots were no more than 2.5 m from the source. The soil surface in each pot was covered with an even layer of seed. The population in each pot was reduced to three plants after germination. Soils were kept moist with distilled water. Ambient temperature was kept at 10 °C by exhaust fans. After 6 months of growth, the seedlings in each pot were harvested, dried, and weighed to the nearest 0.1 g.

Statistical Analysis for Bioassay

An analysis of variance was conducted for each of the four soils. Multiple comparisons were made by use of Duncan's (1955) test. (Tukey's (1953) and Scheffe's (1950) tests provided similar results; only the values for Duncan's test are reported here.) A nutrient was considered deficient if the average weight of the bioassay for pots not receiving that nutrient was significantly less (at alpha = 0.05) than the average weight of pots with all nutrients added.

Results and Discussion

Table 5 summarizes biomass and nutrient capital for the average doghair site at Quilcene. Concentrations of nutrients within individual ecosystem components are discussed in appendix 1. Because standards for the amount of nutrients needed to grow trees on specific soil types have not been developed, we have no direct way of evaluating the amount of capital potentially lost during harvest from Quilcene doghair relative to site productivity. We also do not have nutrient capital estimates for similar stands on similar soils. Therefore, to evaluate our estimates for nutrient capital distribution in Quilcene doghair, we compare our results to nutrient capital estimates developed for other conifer types in the region (table 1, figures 4 through 10).

The amount of biomass in live trees at Quilcene is within the range of biomass values given for other second-growth stands. Individual trees are relatively small for their age. Total aboveground biomass at Quilcene is higher than that for Bigger and Cole's (1983) high site and is comparable to Grier and others' (1974) 450-year-old site. This may be due to differences in stand history. At Quilcene, the stands originated after wildfire that left large amounts of woody debris on the site. The second-growth stands at Pack Forest probably followed a commercial timber harvest and prescribed burn that left little woody debris. Even with these differences, the doghair at Quilcene is average in terms of total biomass production.

Likewise, quantities of nutrient capital for the stands compare favorably with those in other ecosystems. Total aboveground capital for the doghair is on a par with that for the old-growth stand reported by Grier and others (1974). The distribution of capital within the tree, however, seems more in line with the distributions found on the Bigger and Cole (1983) sites. Nutrient capital in the soil is well within the range of values given for other forest types. Hence, what is unique about doghair is not the amount of nutrient capital, but the distribution of that capital. A large portion of it is in dead trees and in the forest floor.

Table 5—Biomass and nutrient budgets averaged over all Quilcene sites

Component	Biomass	N	P	K	Ca	Mg
	Megagrams/ hectare	- - - - - - - - - *Kilograms/hectare* - - - - - - - - -				
Crown	27	135	42	90	164	28
Bole	217	159	41	156	322	49
Total tree above ground	244	294	83	246	486	77
Standing dead	15	14	3	4	27	3
Residue	100	93	20	27	180	20
Forest floor	244	1245	193	219	1234	359
Total above ground	603	1646	299	496	1927	459
Soil (effective rooting depth)	—	4534	3967	444	6691	928

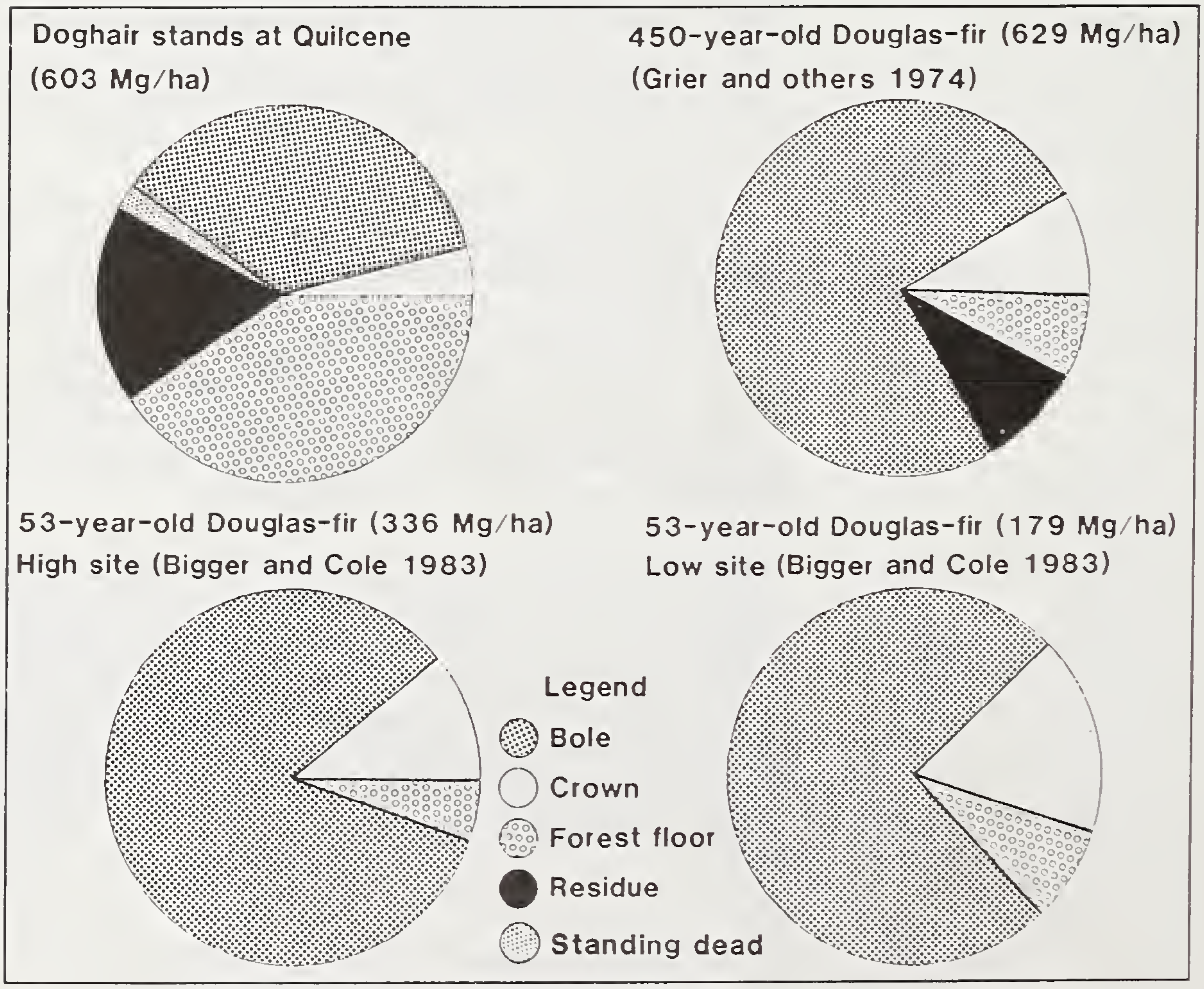

Figure 4—Comparison of biomass by components for Quilcene and published ecosystems.

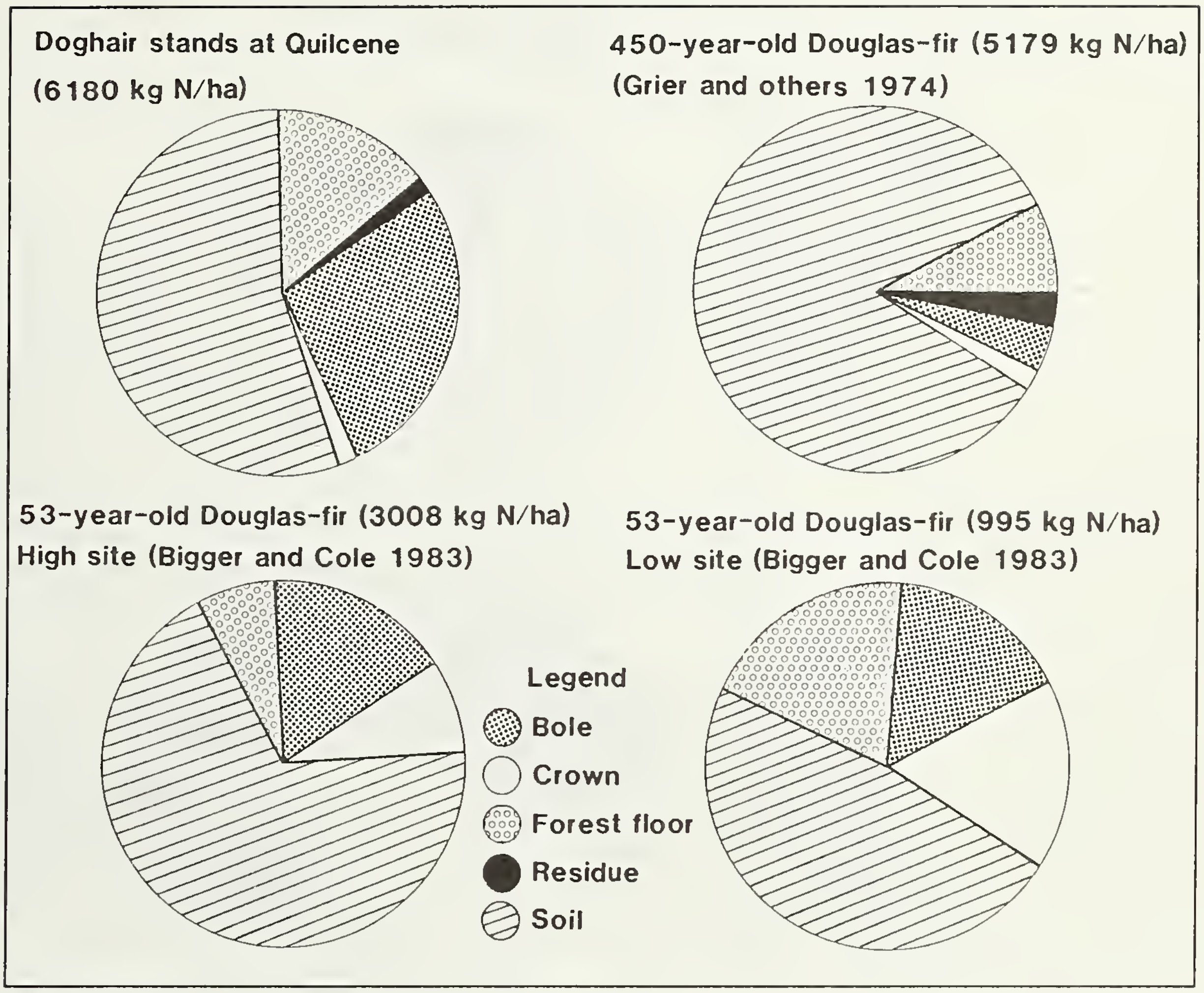

Figure 5—Comparison of nitrogen capital by components for Quilcene and published ecosystems.

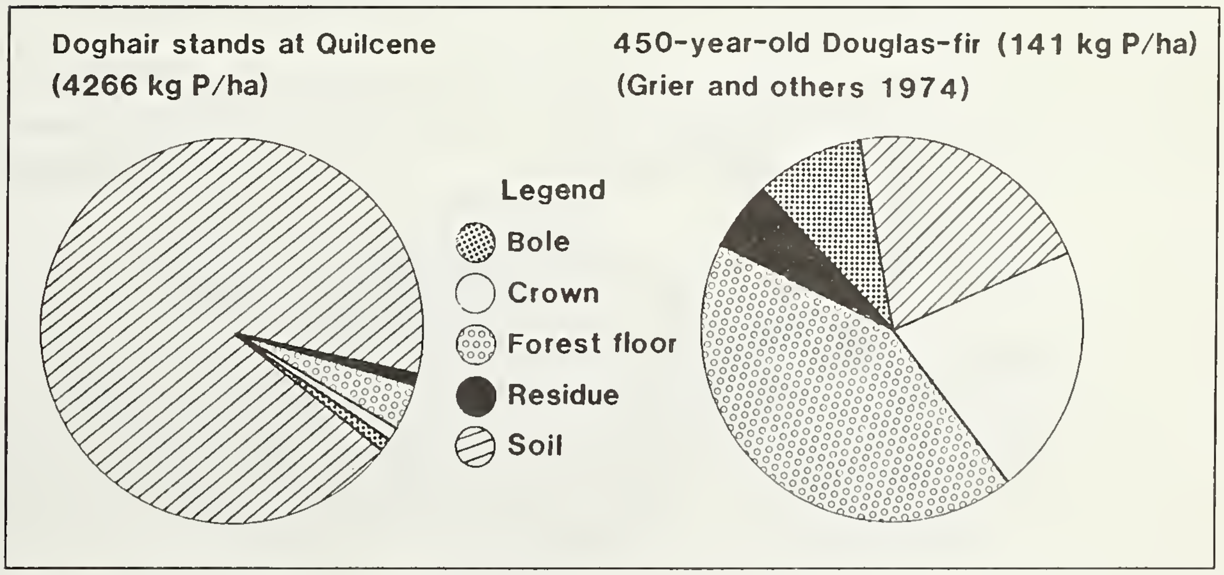

Figure 6—Comparison of phosphorus capital by components for Quilcene and a published ecosystem.

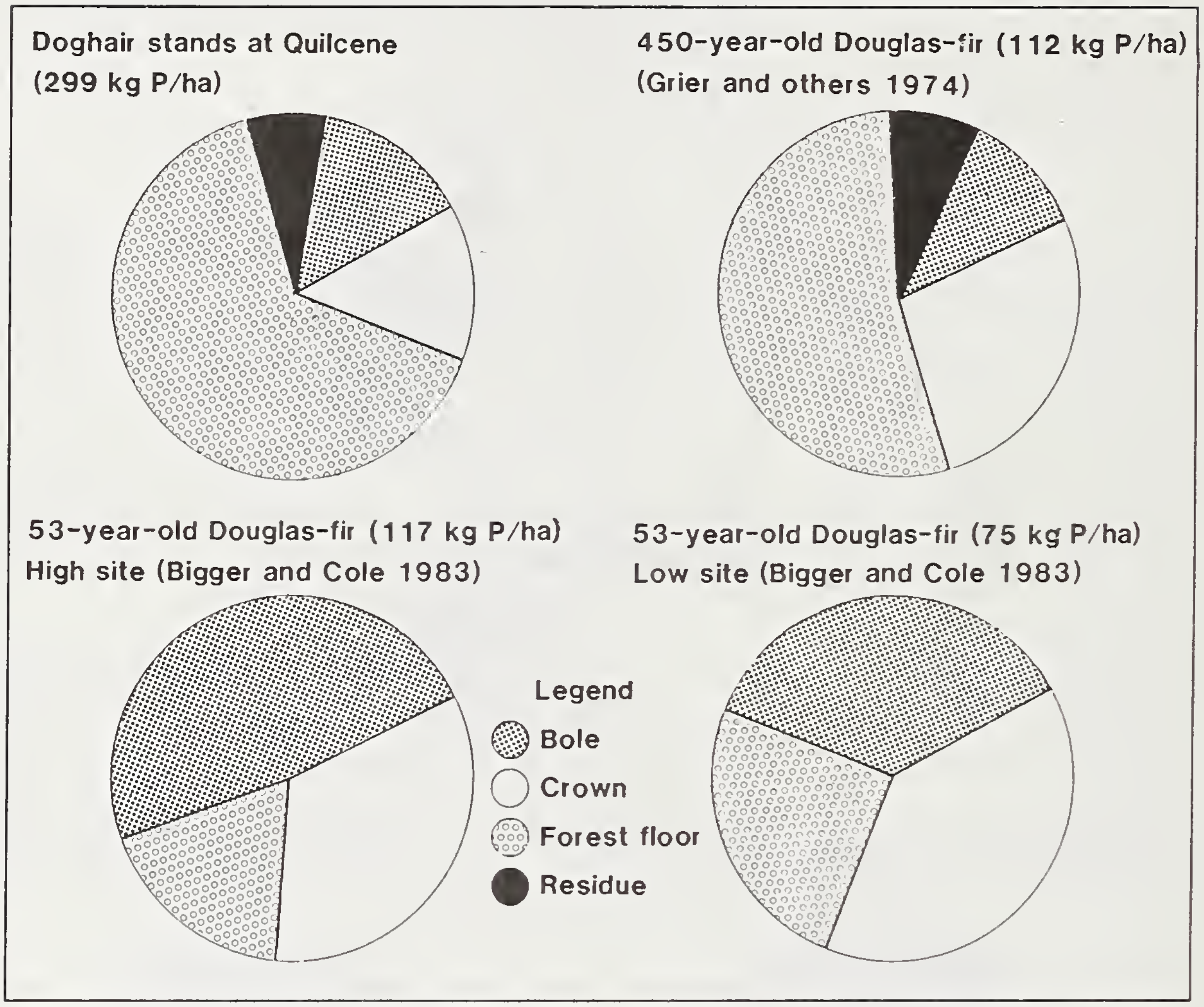

Figure 7—Comparison of phosphorus capital without soil by components for Quilcene and published ecosystems.

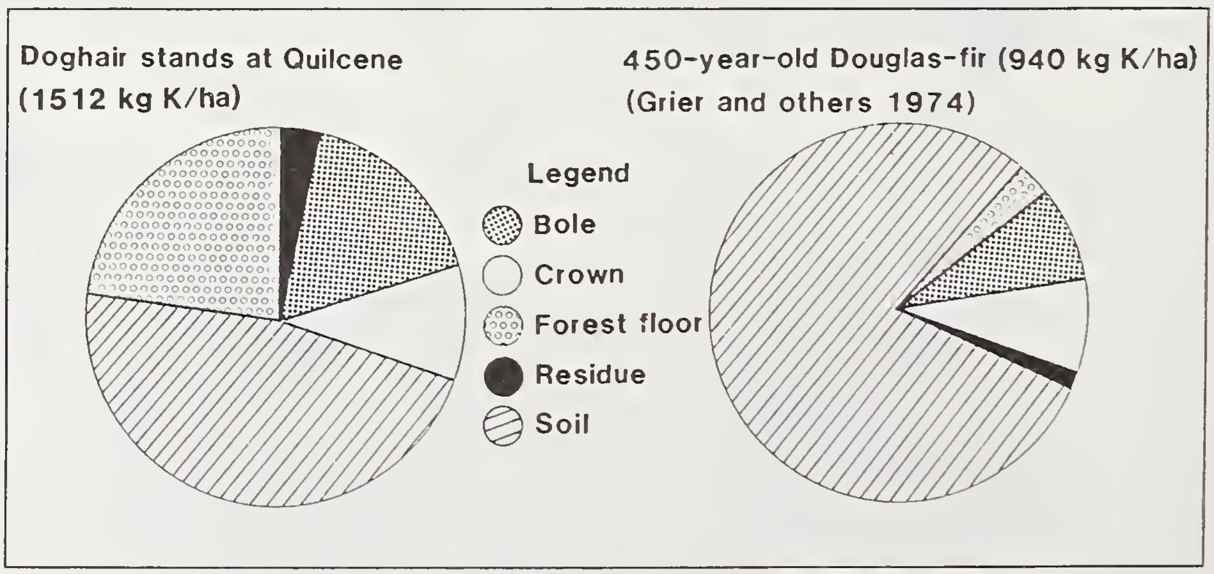

Figure 8—Comparison of potassium capital by components for Quilcene and a published ecosystem.

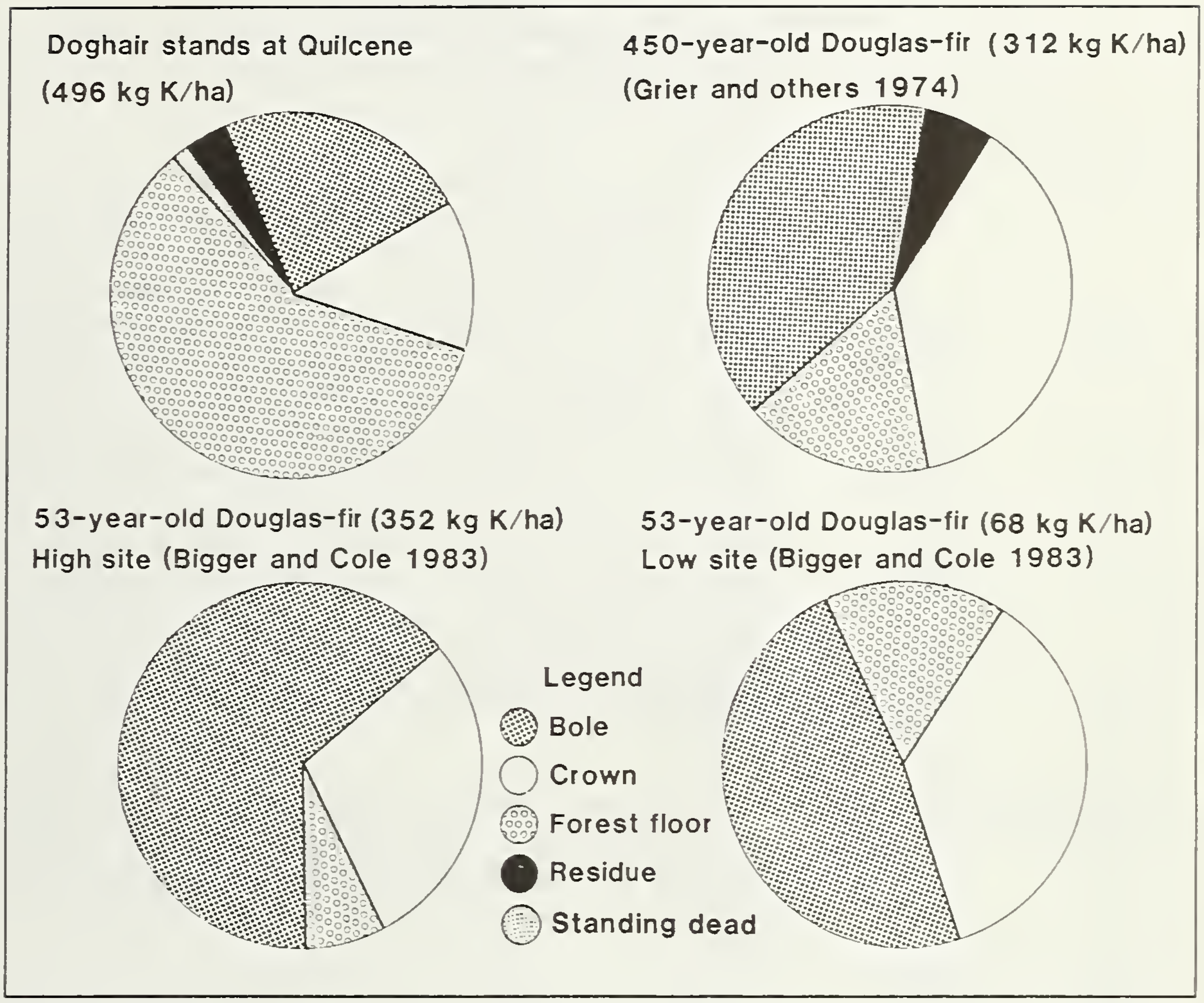

Figure 9—Comparison of potassium capital without soil by components for Quilcene and published ecosystems.

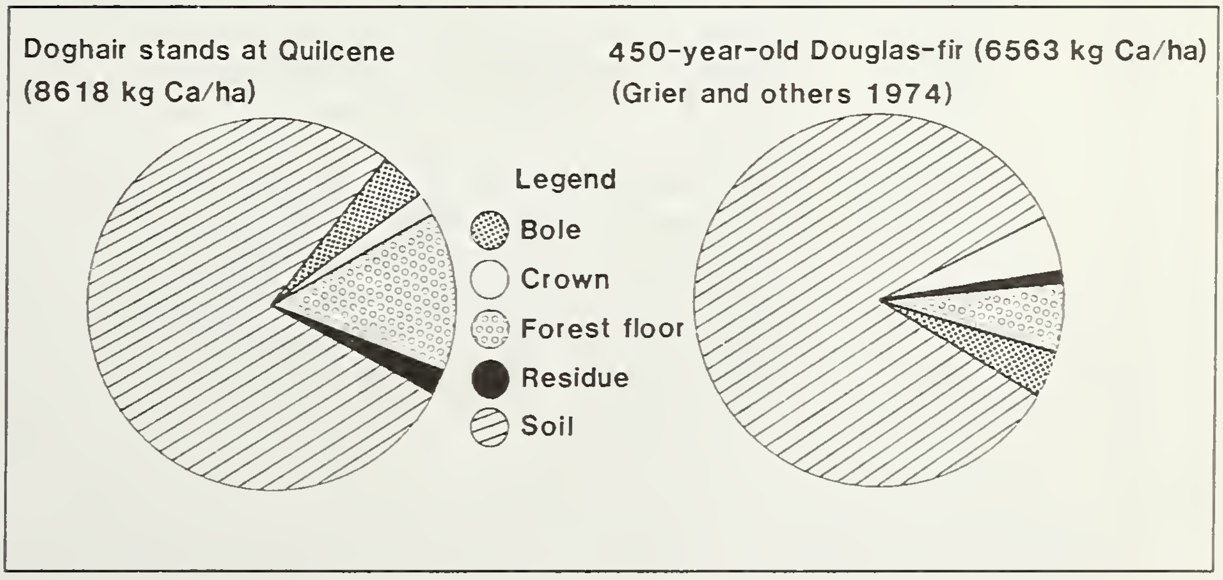

Figure 10—Comparison of calcium capital by components for Quilcene and a published ecosystem.

A description of a "typical" soil profile found on our study sites is presented in appendix 2. Generally, the soils are coarse in texture with large volumes of coarse fragments (greater than 35 percent by volume). Many of the subsurface layers are impermeable, as is evident by the shallow rooting depth (less than 50 cm).

Results of the bioassay are listed in table 6. Analysis of variance was significant (P less than or equal to 0.05) for all sites. Results of multiple comparisons of treatments are illustrated in figure 11. If no nutrients were deficient, we would expect to have no significant difference between treatments. If a treatment (dose of all nutrients except the one in question) had a significantly lower weight than the treatments that included all nutrients, we would conclude that that nutrient was deficient. We expected to see a deficiency in N and tested for two doses of N—184 kg/ha and 368 kg/ha. We therefore expected the –N treatment (all nutrients added except N) to be less than the controls with N added, and the all-nutrient treatments to have the largest weights. As figure 11 illustrates, we did not find the significant differences between treatments that would indicate a deficiency of N. The results showed no consistent deficiency for any of the other nutrients. The weights of the –Mg treatment are high for all soils. We suspect this response is due to a dose of Mg per treatment that was too high for the seedlings rather than a toxicity of Mg on site. Hence, in terms of macronutrient availability under controlled conditions, the soils at Quilcene do not appear to be deficient in nutrients.

Conclusions

In this study, we looked at an isolated portion of the doghair problem: nutrient capital and deficiencies of overstocked sites at Quilcene, Washington. We found that nutrient capital and availability were sufficient for tree growth on these sites. Productivity in terms of optimal product development seems to be primarily a problem of stocking control.

The results of this study provide insight into management implications of whole-tree harvesting of these stands. Because the nutrient capital in living crown materials constitutes a small portion of the total site capital, extracting this material from the site during harvest or site preparation activities should not pose a threat to biomass production in the near future. When harvest and site preparation methods are prescribed, consideration should be given to the amount of nutrient capital currently tied up in dead material and in the forest floor. Likewise, attention should be paid to the effects that management practices may have on the soil physical properties.

Future research should address strategies to regenerate these sites and investigate how harvest and site preparation methods affect stocking of the next stand. We have much to learn about the nutrient resources contained in the root systems of these stands and the role these reserves play in the productivity of the next rotation. The effects of intensive harvesting over several rotations on nutrient capital and productivity have yet to be explored for these sites.

Table 6—Average dry weights of bioassays by treatment[1/]

Treatment name	Eightmile Creek 13	Eightmile Creek 19	Snow Creek 1	Snow Creek 3
		Grams		
Control	0.58 (.26)	0.76 (.11)	0.96 (.21)	1.38 (.34)
Control+N1	1.62 (.37)	1.24 (.60)	1.20 (.37)	1.68 (.33)
Control+N2	1.22 (.48)	1.36 (.42)	.80 (.25)	1.36 (.51)
All-nutrients(N1)	1.82 (1.22)	1.70 (.60)	.92 (.55)	1.76 (.96)
All-nutrients(N2)	1.64 (.40)	1.86 (.78)	.42 (.16)	1.52 (.42)
–N	.94 (.23)	1.16 (.13)	.94 (.27)	.76 (.38)
–Ca	.82 (.24)	1.06 (.60)	.78 (.25)	1.08 (.65)
–Cu	1.32 (.31)	1.48 (.72)	.76 (.26)	1.72 (.62)
–K	1.78 (.54)	1.32 (.75)	.84 (.32)	1.18 (.70)
–Mg	1.88 (.44)	1.80 (1.09)	1.20 (.40)	1.84 (.68)
–P	1.16 (.53)	1.24 (.26)	.56 (.32)	1.34 (.47)
–S	.92 (.51)	1.35 (.19)	.56 (.09)	1.32 (.36)

[1/] Standard deviation is in parentheses. Sample size was 5 pots per treatment except –S for Eightmile Creek 19 (sample size 4); standard errors were within 6 percent of the mean for all sites.

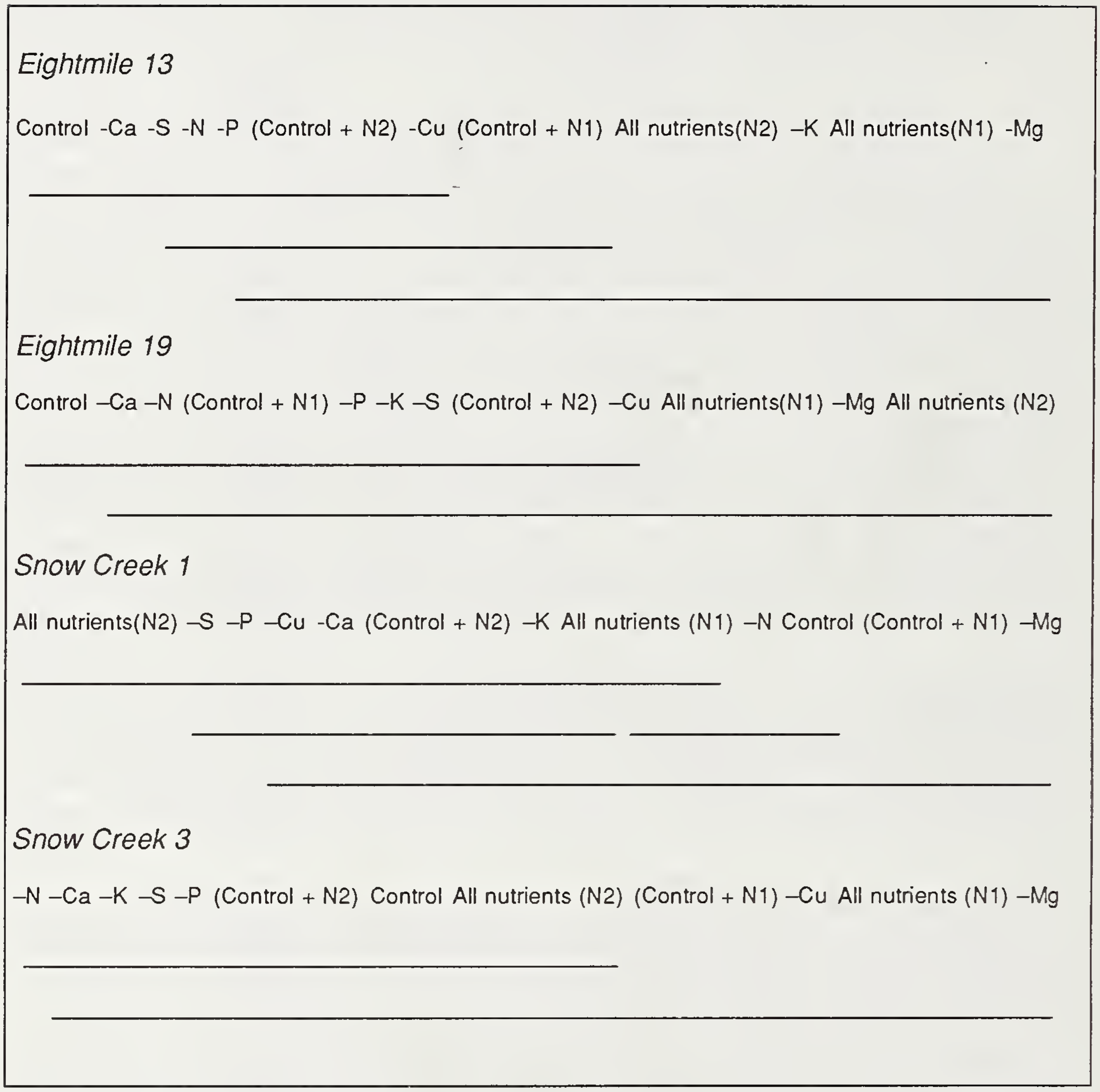

Figure 11—Duncan's multiple comparison of nutrient bioassays; treatments listed in order of increasing average dry weight; treatments over common bar are not significantly different at 95-percent level.

Acknowledgments

Funding for this study was contributed by the U.S. Department of Energy. The Quilcene Ranger Station of the Olympic National Forest provided additional support in laboratory space, study sites, and assistance in all aspects of fieldwork.

Special acknowledgment goes to Julianne K. Bulgrin for her support in the field and laboratory, assistance in data reduction, and illustration.

English Equivalents

When you know	*multiply by*	*to find*
millimeter (mm)	0.0394	inches
centimeters (cm)	0.3937	inches
meters (m)	3.2808	feet
hectares (ha)	2.4711	acres
grams (g)	0.0350	ounces
kilograms (kg)	2.2046	pounds
kilograms/hectare (kg/ha)	0.8926	pounds/acre
megagrams/hectare (Mg/ha)	0.4453	tons/acre
trees/hectare	0.4050	trees/acre
liter	1.057	quarts
degrees Celsius (°C)	1.8 and add 32	degrees Fahrenheit (°F)

References

Bigger, C. Mollie; Cole, Dale W. 1983. Effects of harvesting intensity on nutrient losses and future productivity in high and low productivity red alder and Douglas-fir stands. In: I.U.F.R.O. symposium on forest site and continuous productivity; 1982 August 22-28; Seattle, WA. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station:167-178.

Birkeland, Peter W. 1977. Pedology, weathering, and geomorphological research. New York, NY: Oxford University Press. 285 p.

Blake, G.R. 1965. Bulk density. In: Black, C.A., and others, eds. Methods of soil analysis, part 1. Agronomy 9: 374-390.

Brown, James K. 1974. Handbook for inventorying downed woody material. Gen. Tech. Rep. INT-16. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 24 p.

Brown, Terry Henry. 1977. Nutrient distributions of two eastern Washington forested sites. Pullman, WA: Washington State University. 111 p. Ph. D. thesis.

Chapman, H.D. 1965. Cation exchange capacity. In: Black, C.A., and others, eds. Methods of soil analysis, part 1. Agronomy. 9: 891-901.

Cromack, K., Jr.; Swanson, F.J.; Grier, C.C. 1978. A comparison of harvest methods and their impact on soils and environment in the Pacific Northwest. In: Youngberg, C.T., ed. Forest soils and land use, proceedings of the 5th North American forest soils conference; August 1978; Fort Collins, CO. Fort Collins, CO: Colorado State University, Department of Forestry and Wood Science: 449-476.

Duncan, D.B. 1955. Multiple range and multiple F tests. Biometrics. 11: 1-42.

Gessel, S.P.; Kenady, R.M.; Atkinson, W.A., eds. 1979. Forest fertilization conference; 1979 September 25-27; Union, WA. Inst. For. Resour. 40. Seattle, WA: University of Washington College of Forest Resources. 275 p.

Grier, C.C.; Cole, D.W.; Dyrness, C.T.; Fredriksen, R.L. 1974. Nutrient cycling in 37- and 450-year-old Douglas-fir ecosystems. In: Waring, R.H.; Edmonds, R.L., eds. Integrated research in the coniferous forest biome; CFB Bull. 5. Seattle, WA: University of Washington College of Forest Resources: 21-34.

Jennings, Wesley; May, Meredith; Sheehy, Gwen; Darling, Nancy. 1982. The Olympic National Forest soil resource inventory update report 1982. Olympia, WA: U.S. Department of Agriculture, Forest Service, Olympic National Forest. 158 p.

Kimmins, J.P. 1977. Evaluation of the consequences for future tree productivity of the loss of nutrients in whole tree harvesting. Forest Ecology and Management. 1: 169-183.

Miller, R.E. 1979. Response of Douglas-fir to foliar fertilization. In: Gessel, S.P.; Kenady, R.M.; Atkinson, W.A., eds. Forest fertilization conference; 1979 September 25-27; Union, WA. Inst. For. Resour. 40. Seattle, WA: University of Washington College of Forest Resources: 62-68.

Morrison, Ian K.; Foster, Neil W. 1979. Biomass and element removal by complete-tree harvesting of medium rotation forest stands. In: Impact of intensive harvesting on forest nutrient cycling; 1979 August 13-16; Syracuse, NY. Syracuse, NY: State University of New York, College of Environmental Science and Forestry: 111-129.

Norton, Stephen A.; Young, Harold E. 1976. Forest biomass utilization and nutrient budgets. In: Oslo biomass studies. Orono, ME. University of Maine Press: 55-73.

Ovington, J.D.; Madgwick, H.A.I. 1959. Distribution of organic matter and plant nutrients in a plantation of Scots pine. Forest Science. 5: 344-355.

Pong, W.Y.; Waddell, D.R. 1986. Harvesting overstocked stands of small diameter trees. Report 1: Stem density of western hemlock, Douglas-fir, and western redcedar; and Report 2: Biomass distributions of western hemlock, Douglas-fir, and western redcedar. Reports to the U.S. Department of Energy. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Scheffe, H. 1950. Statistical methods for evaluation of several constants and several sources of variability. Chemical Engineering Progress. 50: 200-205.

Switzer, G.L.; Nelson, L.E.; Smithe, W.H. 1968. The mineral cycle in forest stands. In: Forest fertilization—theory and practice. Muscle Shoals, AL: Tennessee Valley Authority: 1-9.

Tukey, J.W. 1953. The problem of multiple comparisons. Princeton, NJ: Princeton University.

U.S. Department of Agriculture. 1975. Soil taxonomy. Agric. Handb. 436. Washington DC: U.S. Department of Agriculture, Soil Conservation Service. 754 p.

Van Hook, R.I.; Johnson, D.W.; West, D.C.; Mann, L.K. 1982. Environmental effects of harvesting forests for energy. Forest Ecology and Management. 4: 79-94.

Vitousek, P.M. 1981. Clearcutting and the nitrogen cycle. In: Clark, F.E.; Rosswall, T., eds. Terrestrial nitrogen cycles. Ecological Bulletin (Stockholm). 33: 631-642.

Walsh, L.M.; Beaton, J.D. 1973. Soil testing and plant analysis. Madison, WI: Soil Science Society of America, Inc. 491 p.

Appendix 1

Concentrations of Nutrients by Ecosystem Components

Tables 7 through 10 list nutrient concentrations that have been averaged for all sample trees by component (crown, bole, bark) for each species. Concentrations were weighted by taking the average for all diameters of component nutrient capital divided by component weight. For crowns, the sum of individual stratum concentrations times the corresponding stratum weights was divided by the sum of stratum weights for each tree. The resulting concentrations were then averaged for all trees sampled by individual species.

Nutrient concentrations for individual components by diameter class are illustrated in figures 12 through 16. Concentrations did not vary with diameter for most components. Notable exceptions were concentrations in bark. Nitrogen and calcium increased with diameter; phosphorus decreased. Phosphorus tended to increase with diameter in small crown material.

Few data are published on nutrient concentrations relative to diameter at breast height for trees of similar age growing on the same soil. Ovington and Madgwick (1959) reported nutrient concentrations for 20 Scotch pine (*Pinus sylvestris* L.) trees in a 35-year-old plantation. They show a similar lack of trend for most nutrients and tree components. They did find a decrease in nitrogen concentration with increasing diameter for needles and live trees. They did not report concentrations for bark.

Table 7—Weighted average of nutrient concentrations by component for western hemlock, standard error (in parentheses), and sample size

Component	Unit	N	P	K	Ca	Mg
Crown material less than 0.6 cm in diameter	Percent	0.692	0.243	0.491	0.636	0.142
	Percent	(.221)	(.084)	(.222)	(.209)	(.050)
	Number of trees	12	12	12	12	12
Crown material greater than 0.6 cm in diameter	Percent	.149	.037	.013	.278	.038
	Percent	(.053)	(.013)	(.040)	(.106)	(.014)
	Number of trees	11	11	11	11	11
Bole wood	Percent	.054	.016	.050	.110	.018
	Percent	(.016)	(.005)	(.016)	(.033)	(.006)
	Number of trees	12	12	12	12	12
Bark	Percent	.204	.061	.325	.327	.050
	Percent	(.073)	(.019)	(.104)	(.123)	(.017)
	Number of trees	12	12	12	12	12

Table 8—Weighted average of nutrient concentrations by component for Douglas-fir, standard error (in parentheses), and sample size

Component	Unit	N	P	K	Ca	Mg
Crown material less than 0.6 cm in diameter	Percent	0.684	0.211	0.403	1.024	0.162
	Percent	(.198)	(.066)	(.125)	(.331)	(.050)
	Number of trees	12	12	12	12	12
Crown material greater than 0.6 cm in diameter	Percent	.211	.055	.146	.580	.059
	Percent	(.069)	(.019)	(.050)	(.184)	(.019)
	Number of trees	10	10	10	10	10
Bole wood	Percent	.050	.012	.041	.103	.017
	Percent	(.017)	(.004)	(.019)	(.034)	(.006)
	Number of trees	12	12	12	12	12
Bark	Percent	.206	.054	.187	.379	.045
	Percent	(.063)	(.016)	(.059)	(.146)	(.017)
	Number of trees	12	12	12	12	12

Table 9—Weighted average of nutrient concentrations by component for western redcedar, standard error (in parentheses), and sample size

Component	Unit	N	P	K	Ca	Mg
Crown material less than 0.6 cm in diameter	Percent	0.815	0.144	0.458	1.210	0.133
	Percent	(.234)	(.045)	(.157)	(.362)	(.042)
	Number of trees	9	9	9	9	9
Crown material greater than 0.6 cm in diameter	Percent	.167	.035	.147	.601	.041
	Percent	(.057)	(.012)	(.065)	(.195)	(.014)
	Number of trees	8	8	8	8	8
Bole wood	Percent	.066	.012	.045	.173	.020
	Percent	(.022)	(.004)	(.019)	(.060)	(.007)
	Number of trees	9	9	9	9	9
Bark	Percent	.245	.039	.275	.834	.063
	Percent	(.102)	(.016)	(.123)	(.381)	(.027)
	Number of trees	9	9	9	9	9

Table 10—Weighted average of nutrient concentrations by component for residue (dead trees and logs) and forest floor, standard error (in parentheses), and sample size

Component	Unit	N	P	K	Ca	Mg
Residue:						
Bole wood	Percent	0.049	0.010	0.012	0.098	0.014
	Percent	(.014)	(.004)	(.007)	(.033)	(.005)
	Number of trees	24	24	24	24	24
Bark	Percent	.309	.045	.088	.303	.045
	Percent	(.100)	(.013)	(.043)	(.110)	(.016)
	Number of trees	24	24	24	24	24
Forest floor	Percent	.510	.079	.090	.506	.147
	Percent	(.116)	(.016)	(.021)	(.123)	(.050)
	Number of trees	24	24	24	24	24

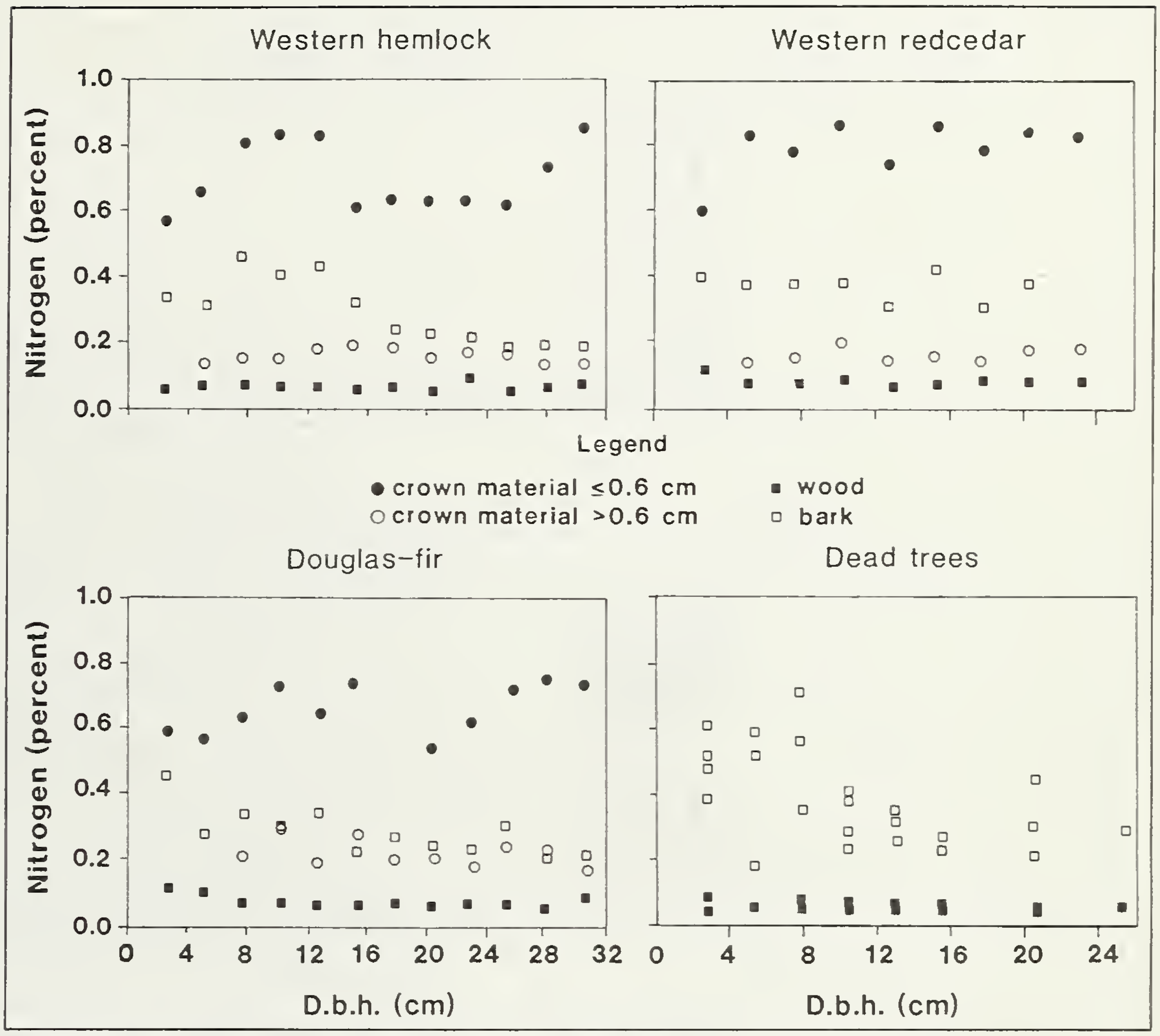

Figure 12—Concentrations of nitrogen by species and diameter.

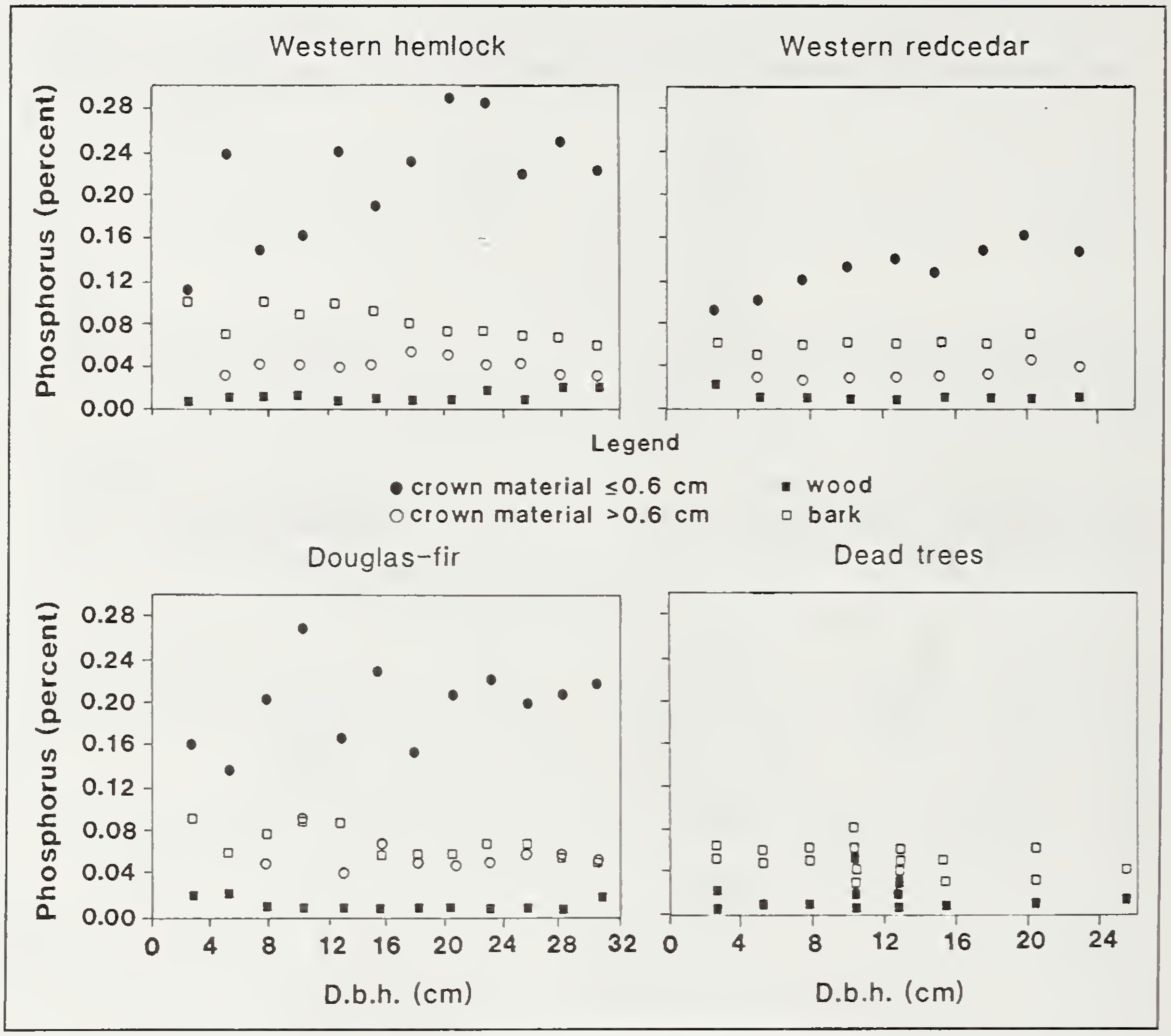

Figure 13—Concentrations of phosphorus by species and diameter.

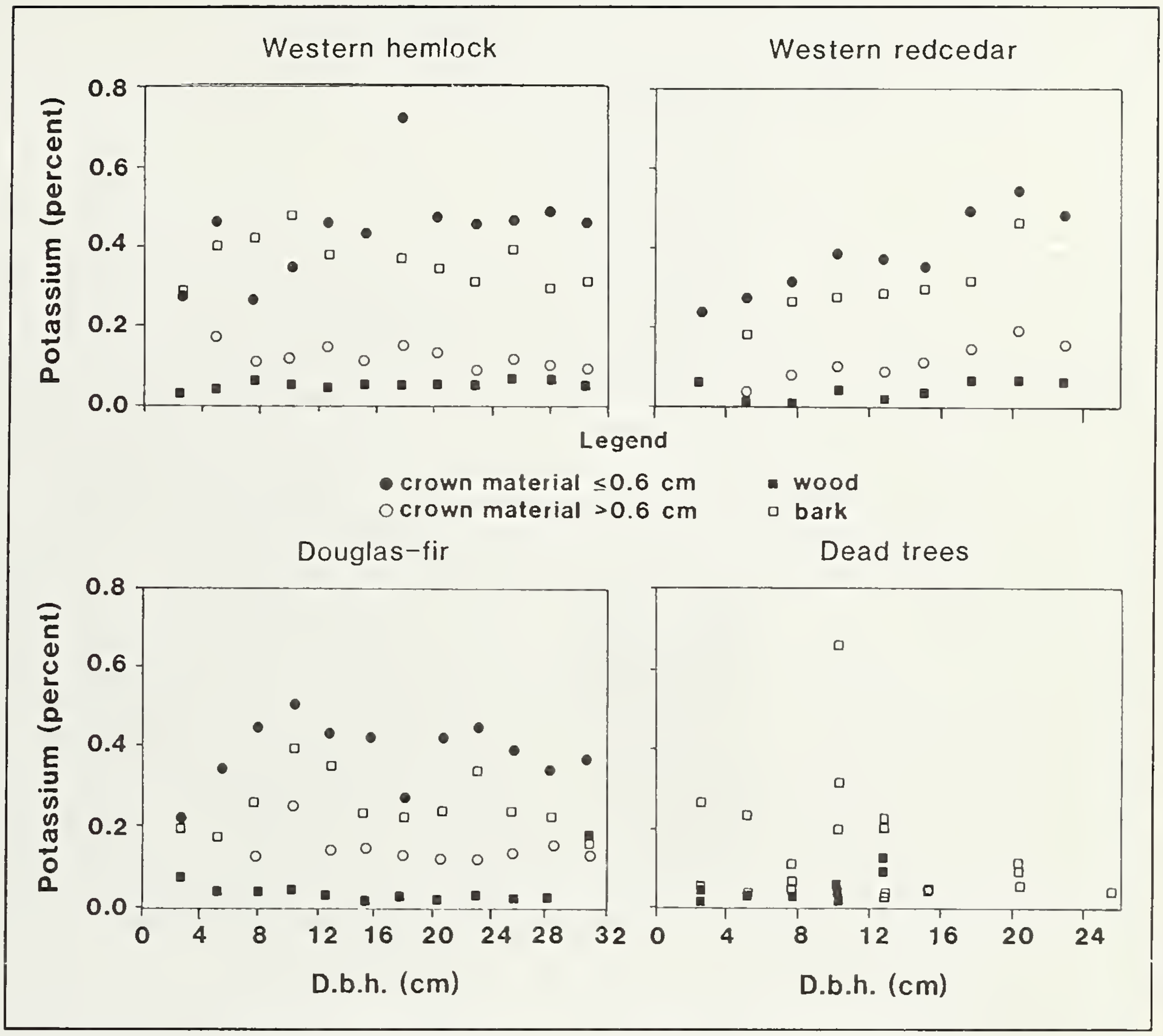

Figure 14—Concentrations of potassium by species and diameter.

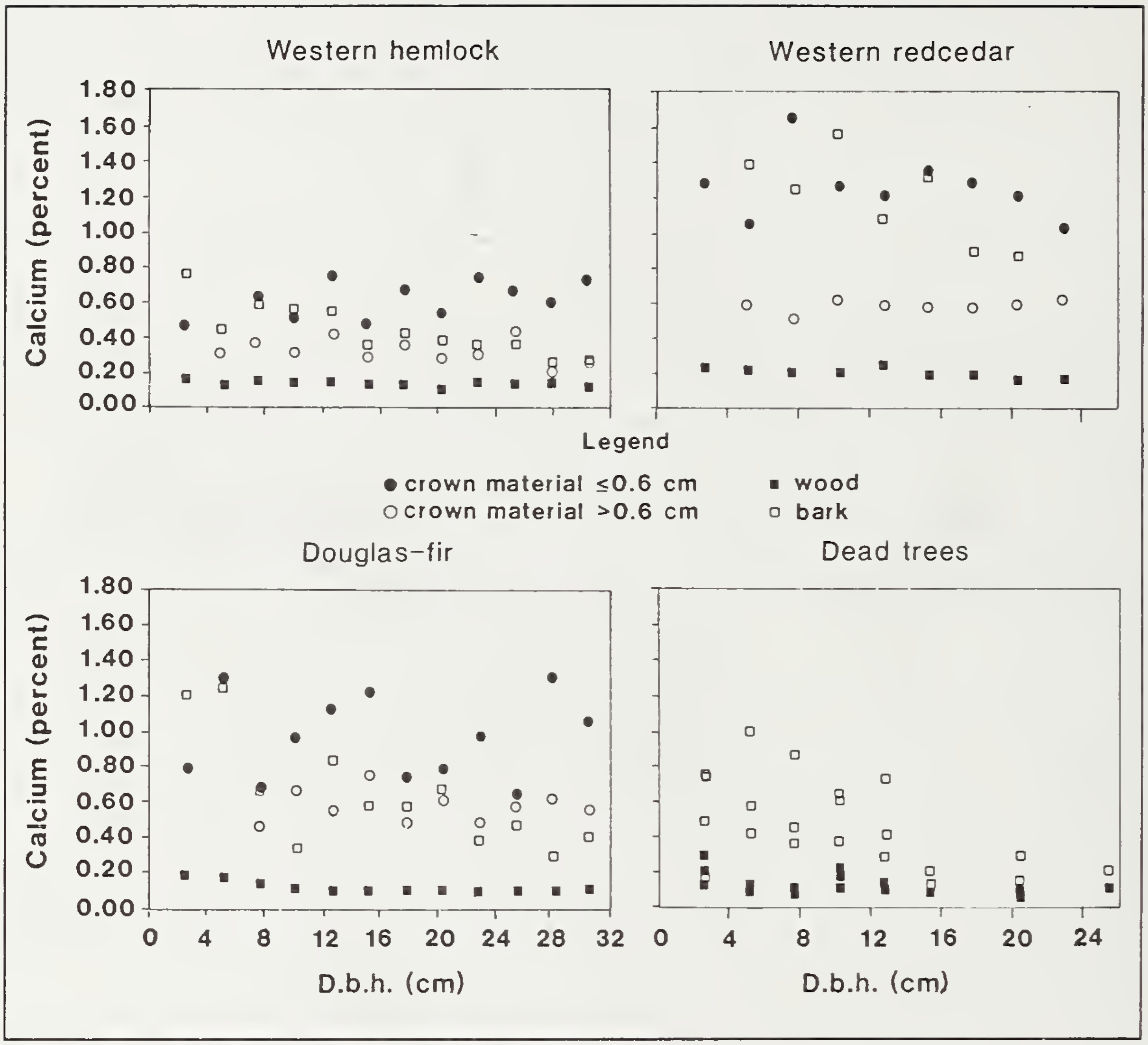

Figure 15—Concentrations of calcium by species and diameter.

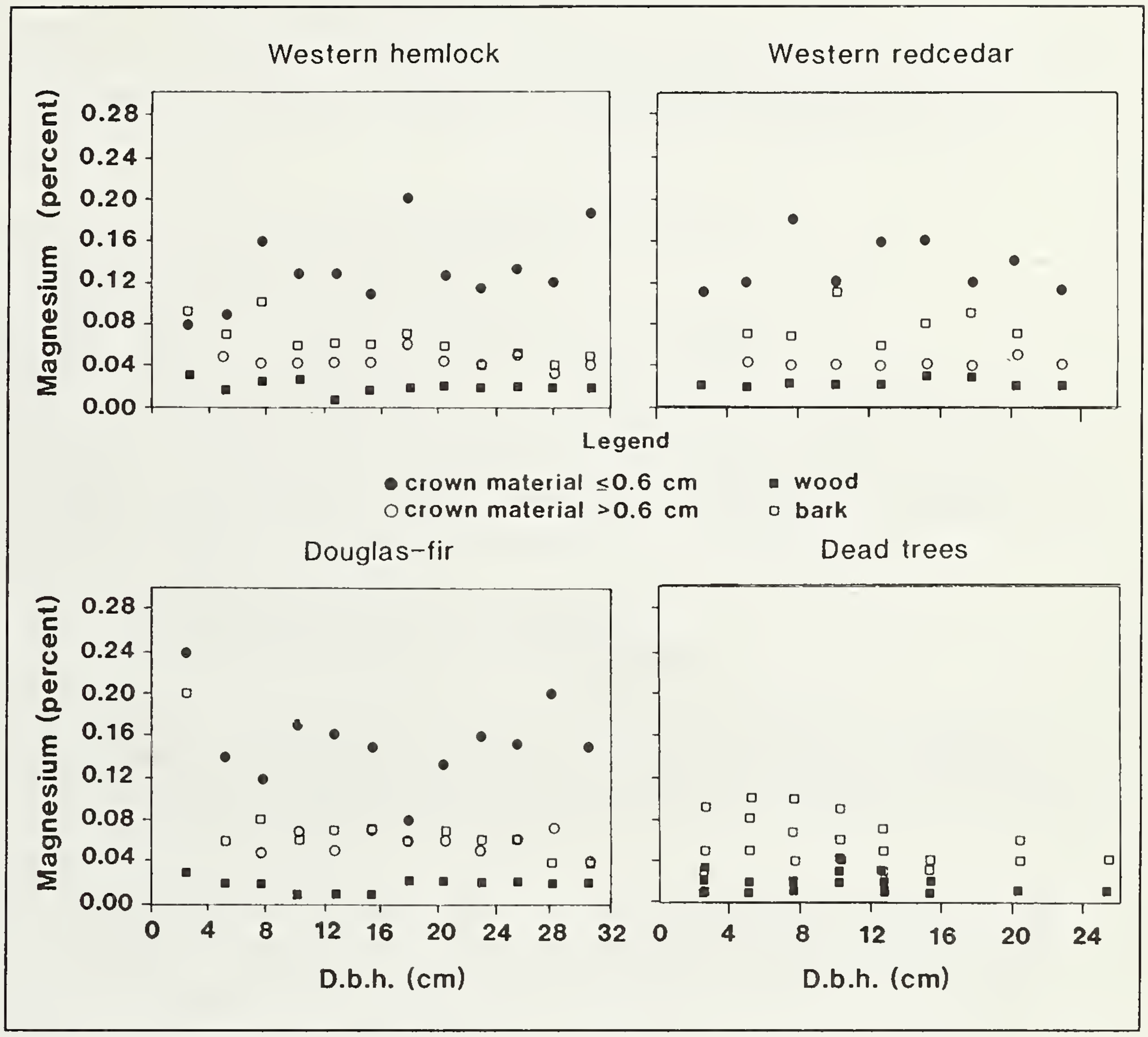

Figure 16—Concentrations of magnesium by species and diameter.

Appendix 2

Description of Soil Profile

Classification: See remarks.

Location: Clallam County, Washington. 11 km north of Quilcene, about 6.5 km west of Highway 101, on the Olympic National Forest. South of the 2814-2847 intersection on road 2847. Soil profile is located 76 m north of the road. SE1/4NE1/4 sec.18, R. 2 W., T. 28 N.

Physiographic position: Ridge side slope, 610-m elevation.

Topography: Undulating 15-percent slope.

Drainage: Moderately well drained.

Vegetation: Western hemlock, Douglas-fir, western redcedar.

Sampled by: Dale R. Waddell.

Remarks: Classification of profiles in this area is not consistent with concepts presented in U.S. Department of Agriculture (1975). Generally, the soils have characteristics of the Orthent suborder grading into the Ochrept suborder. Water movement in the surface horizon is rapid with significant slowing in the subsurface layers. Subsoils are compacted with evidence of some form of cementation.

01 15-3 cm. Conifer branches and needles.

02 3-0 cm. Partially decomposed conifer needles.

A 0-50 cm. Dark yellowish brown (10YR 4/4) gravelly sandy loam, yellowish brown (10YR 5/4) dry; fine granular to weak fine subangular blocky structure; loose (dry), very friable (moist), sticky, slightly plastic (wet); abundant roots in all sizes; clear wavy boundary; pH 5.4.

C 50-254 cm. Dark yellowish brown (10YR 4/4) gravelly sandy loam with light brown gray (10YR 6/2); few fine mottles, light yellowish brown (10YR 5/6) dry; massive; soft (dry), friable (moist), sticky, slightly plastic (wet); few medium roots; gradual irregular boundary; pH 6.0.

Little, Susan N.; Waddell, Dale R. 1987. Highly stocked coniferous stands on the Olympic Peninsula: chemical composition and implications for harvest strategy. Res. Pap. PNW-RP-384. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 29 p.

This report presents an assessment of macronutrients and their distribution within highly stocked, stagnant stands of mixed conifers on the Quilcene Ranger District, Olympic National Forest, northwest Washington. These stands consisted of predominantly three species: western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), and western redcedar (*Thuja plicata* Donn ex D. Don). Preliminary investigation suggests that the living crown contains a small portion of the nutrient capital on the site. Extracting this material from the site during harvest or site preparation should not pose a threat to future production of biomass. Bioassays suggested that no macronutrients were deficient for growth of Douglas-fir seedlings. This study was one of several conducted on the Quilcene Ranger District for a better understanding of the economics, technology, and impacts of harvesting highly stocked, small-diameter timber.

Keywords: Whole-tree logging, nutrient budgets, site productivity, Washington (Olympic Peninsula), Olympic Peninsula—Washington.

Pacific Northwest Research Station
319 S.W. Pine St.
P. O. Box 3890
Portland, Oregon 97208

October 1987

U.S. Department of Agriculture
Pacific Northwest Research Station
319 S.W. Pine Street
P.O. Box 3890
Portland, Oregon 97208

BULK RATE
POSTAGE +
FEES PAID
USDA-FS
PERMIT No. G-40

do NOT detach label